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Cement-air jet as an efficiency factor of technologies for manufacturing mixed concrete reinforcing elements (pales)

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Abstract. The results of the evaluation of known technologies for the manufacture of soil-concrete piles for strengthening the underground space are presented. It is proposed the method in which a multifunctional cement-air jet is used as a working body instead of a mortar pipeline in traditional drilling and mixing equipment. Piles formed using a cement-air jet have improved compressive strength (up to 12.09 MPa) and additional cross-section increase up to 100%, which is a consequence of the designed cement supply and reduced water-cement ratio. The influence of cement mortar injection parameters, in particular pressure and dosage, as well as the design features of the drilling system, which ensure uniform saturation, are studied. The obtained data confirm the prospects of using the proposed technology for strengthening the foundations of foundations and increasing the efficiency of soil-concrete reinforcement while reducing material, labor and technical costs.

1 Introduction

In the practice of construction and construction and reconstruction works, the improvement of the strength and other characteristics of the underground space belongs to the technologies of reinforcement with soil-cement elements in the form of piles, made directly in the soil. Two main methods are used: the so-called soil-mixing using the mechanical energy of drilling equipment [1,2] and jet based on the energy of high-pressure jets of cement mortar without or together with water and compressed air [3,4,5].

A comprehensive approach to evaluating known technologies reveals their certain advantages and disadvantages. In jet technologies, the working cycle is implemented by cutting the soil with a high-pressure jet of cement mortar and mixing them directly in the well. If necessary, to enhance the work of the cement jet, jets of water and compressed air are added [6,7]. To implement the technology, unique equipment is required that can create a pressure of 20…40 MPa. The advantages of jet technologies include increased strength up to 8 MPa, an increase in the size of piles (up to 3 m in diameter and more than 40 m in height). Multi-purpose purpose [8].

The disadvantages of the technology include [9, 10] the need for special high-pressure equipment, excessive energy consumption for the operation of special equipment, the possibility of soil erosion, plastic deformations, the emergence of a thinned soil-cement mixture to the surface, the risks of damage to adjacent objects due to high pressure and subsidence of highly hydrated soil.

Drilling-mixing technologies include the development of a well without bringing the soil to the surface with simultaneous injection of cement mortar [11] or during the reverse movement of the drill rod [12,13,14,15]. In both variants, the mixing of the formed mixtures occurs due to devices on the rotating drill rod. The parameters of the manufactured soil-concrete elements (piles) determine the dimensions of the drilling tool, methods of manufacturing the well, volumes and composition of the injected cement mortar, types of soils. Depending on the above factors, the strength varies in the range of 1.23…6 MPa [1,15] with smaller parameters of piles with cross-sectional dimensions of 0.5…0.7 m, column height of 6…7 m, which is somewhat less in relation to (compared to) jet piles.

Drilling mixing technologies are endowed with some advantages [1,14,15], including cost-effectiveness, simplified equipment and maintenance, high productivity, versatility, safety.

All of the listed technologies are characterized by an increased water content in the soil-cement mixture and the complexity of the processes of reducing the water-cement ratio.

2 Problem statement

A promising direction for solving the problem of resource conservation in soil-concrete pile technologies should be the use of a multifunctional cement-air jet as a working body of traditional equipment, which will provide the ability to supply the designed amount of binder and bring the water-cement ratio to the optimal level.

To achieve the set goal, it is necessary to solve the following tasks:

– perform a comparative analysis of jet and drill-mixing technologies and identify resources for increasing their efficiency;

– determine and justify the suitability of the cement-air jet to increase the strength of soil concrete due to the designed saturation of loose soil with binder and the provided opportunity to reduce the water-cement ratio to the optimal level as conditions for reducing the number of piles while improving the characteristics of the underground space;

– assess the ability of the cement-air jet to combine the functions of cutting soil from the walls of a pre-designed well as a factor in increasing the cross-section of soil-concrete piles and their bearing capacity;

– confirm the feasibility of the designed technology to regulate the water-cement ratio in accordance with the needs of soil concrete.

3 Materials and research methods

To determine the prospects of resource-saving suitability of cement-air jet in the processes of manufacturing soil-concrete piles, a study of experimental samples was conducted, which were manufactured using specially proposed equipment (Fig. 1). Its constructive solution allows you to simulate the production processes of most known industrial equipment and include in the production processes the operation of cement-air jet as a working body, cement and water dispensers, and means of fixing the height of the drill rod lift.

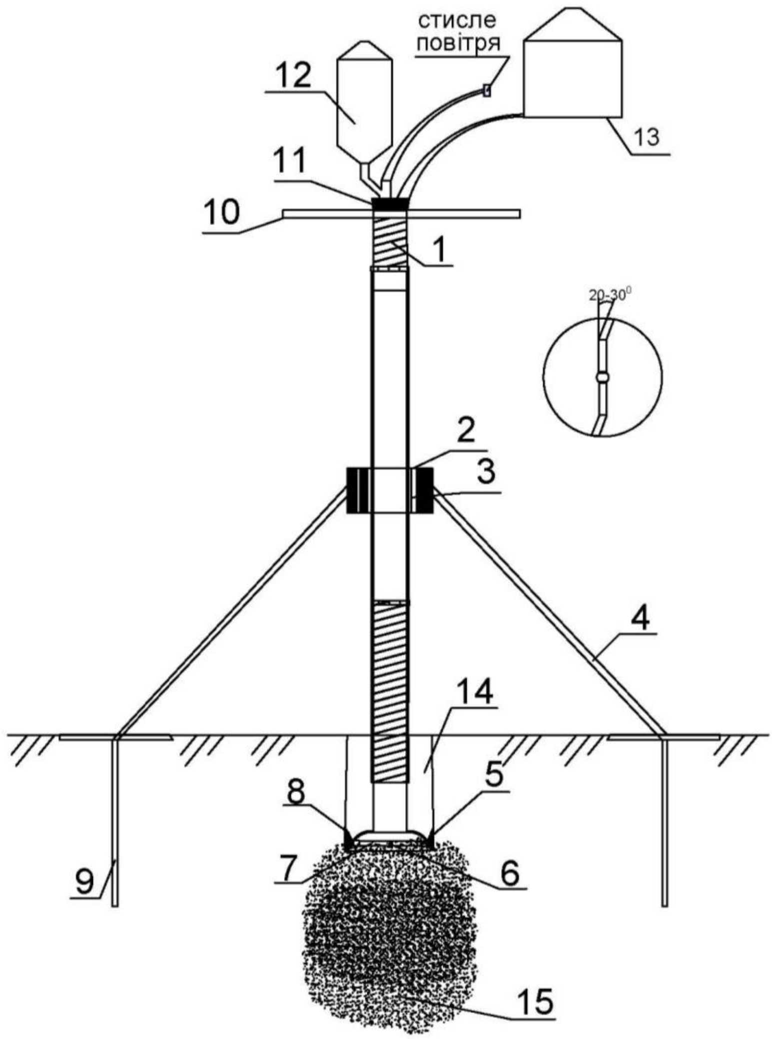

Fig.1. Device for manufacturing soil-concrete piles (elements) using cement-air jet and dosed volume of hydration water:

1 - hollow drill rod;
2 - nut;
3 - fastening clip;
4 - support;
5 - drill bit;
6 - water hole;
7 - cement-air jet nozzle;
8 - cement-air jet;
9 - fixing anchor;
10 - rotation handle;
11 - union nut;
12 - cement container
13 - water dispenser;
14 - pre-made well;
15 - soil-cement mixture (soil-concrete)

The algorithm for manufacturing an experimental pile is as follows. After the completion of the well development, at the moment of the start of the reverse movement of the drill rod, the action of the cement-air jet begins, which is designed to perform the functions of the designed supply of binder, cutting soil from the walls of the well, and homogenization of the formed soil mixture, which contains the adjusted moisture content.

The above measures for the manufacture of soil-concrete piles (elements) are intended to give the cement-air jet the ability to reduce the resource intensity of products, and due to their improved characteristics to reduce the number of piles as reinforcing elements of soil masses, which ultimately may indicate a reduction in machine and labor time.

In addition to the designed supply of cement, an option for the required moistening of the soil mixture is provided, for which water is supplied in specified volumes as an addition to the natural moistening of the soil after appropriate measurements.

The determination of the resource-saving suitability of the cement-air jet in this technology was carried out in relation to the element formed using the above-mentioned device. The results of the research are also intended to evaluate the cutting and cement-supplying functions of the jet. The water supply channel available in the device allows maintaining a given water-cement ratio.

Similar to traditional technologies, the experimental pile was made in a pre-developed well without removing the soil consisting of sandy loam. Portland cement grade 400 (CEM I 32.5) was used as the binding component, and the mixing water was tap water. The cement content in the soil-cement mixture varied in each manufactured well and in three zones of a fixed height of a separate well at the rate of 200, 325, 400 kg/m^3 of soil. The water-cement ratio was W/C=0.29…0.30 taking into account the previously determined natural soil moisture and was adjusted by additional dosing.

For each pile and zones of a separate manufactured pile, the design mass of Portland cement was used with an accuracy of ± 1 g and water with an accuracy of ± 1 ml.

In the case of manufacturing a separate pile, the height of each zone was measured using a measuring ruler and marks on the outer surface of the drill rod. The duration of manufacturing such pile sections was recorded with a chronometer, and their cross-section was established using a tape measure with an accuracy of ± 1 cm after 28 days of exposure in the soil.

Samples for determining the strength were prepared from different sections of a separately manufactured soil concrete pile after the design aging. The studied samples in all piles were cut using a hand saw in different places in height and distance from the outer surface. For each series of tests, 6 samples measuring 4x4x4 cm were prepared. The strength corresponded to the average test results of four samples without taking into account the smallest and largest values.

The studies used methods of observation, measurement and testing for the strength of the formed samples, evaluated the macrostructure and cross-section of piles as indicators of increasing the overall bearing capacity. An analysis of physical and mechanical properties was carried out and conclusions were drawn about their relationships with the degree of saturation of the developed soil with cement, which, in turn, allowed us to confirm the hypothesis about the possibility of improving the operational characteristics of piles as a factor in saving costs when reinforcing soil masses.

4 Results and discussion

The results of evaluating the efficiency of the cement-air jet are determined by the indicators of the strength of the soil concrete and the increase in the cross-section of the piles in relation to the well and are given in Table 1 and Fig. 2.

Table 1. Characteristics of soil concrete piles manufactured using the cement-air jet with a pressure of 0.4 MPa and a water-cement ratio of 0.29...0.30.

No.	Characteristics of pile manufacturing parameters			Pile property parameters	
	Cement content, kg/m3 of soil	W/C, d.o.	Jet pressure, MPa	Compressive strength, MPa	Increase in pile cross-section relative to the well, times
1	200	0,33	0,4	5,58	1,45
2	325	0,33	0,4	8,86	1,42
3	400	0,33	0,4	12,90	1,48

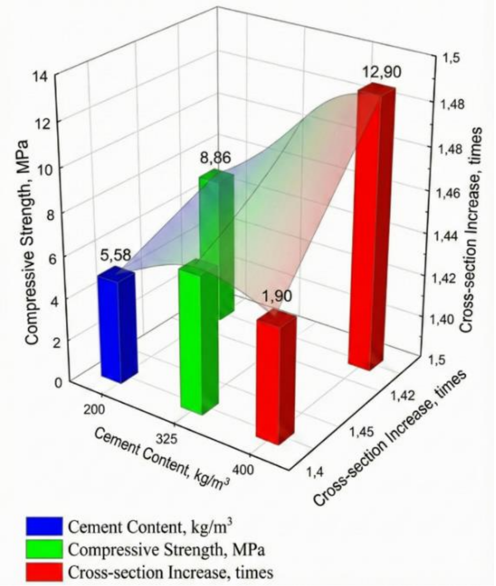

Fig. 2. Graphs of dependences of parameters of soil concrete piles on the technological process at a cement-air jet pressure of 0.4 MPa and a water-cement ratio of 0.29…0.30.

The results of tests of experimental piles manufactured in accordance with the proposed algorithm, which includes the action of a cement-air jet and a water supply channel in the production processes and creates favorable conditions for the formation of higher-quality soil-concrete products, are presented. First, cutting the soil from the walls of a pre-made well is a factor in increasing the pile cross-section. Thus, at a pressure of 0.4 MPa in the air duct, the pile cross-section increased from 100 to 140…160 mm, which indicates the possibility of a subsequent increase in this indicator in the event of an increase in pressure to 0.6 MPa. Second, the ability of the jet to introduce a dosed content of binder into the soil as a factor in strengthening soil concrete is successfully implemented. In the experiment, the cement content was regulated at the rate of 200, 325, 400 kg/m^3 of soil. Strengthening is also facilitated by maintaining a dosed water-cement ratio, which together allowed improving the strength from 5.58 to 12.90 MPa. At the same time, due to the reciprocating motion of the jet, the possibility of further strengthening the soil concrete by supplying the calculated cement content is considered promising.

The significance of the results and their support follow from the analysis and comparative evaluation of the proposed method and basic technologies that provide strength in the range of 1.5…9 MPa [1,8].

Comparative analysis of information sources, practice data, systematization of results and their evaluation revealed a certain priority of soil concrete pile manufacturing technologies as important means of solving problems of underground space development by reinforcing with the mentioned products, which is due to the needs of construction and reconstruction [2,5,6].

Further development of soil concrete technologies can be aimed at in-depth use of the available resource based on the identification of problematic shortcomings and effective measures to eliminate them.

The main identified shortcomings of traditional technologies, which have increased costs and which hinder the further effective use of soil concrete structures, include insufficient strength of the material, which causes significant problems in the event of the need to strengthen soil masses, arrange foundations of buildings and structures or during their reconstruction. The lack of methods for regulated introduction of cement into the soil mixture creates a problem of primary solution. Negative consequences are also associated with the need to inject cement mortar into the soil mixture, which leads to excessive water saturation, porosity and a decrease in the strength of products when using traditional drilling and mixing technologies. The consequences of these shortcomings cause the need to use additional piles to provide the necessary characteristics to the underground space, which leads to a decrease in productivity, an increase in the duration of work, additional costs of working time, energy, operation of mechanisms, i.e. a deterioration in technical and economic indicators.

It is likely that the solution of the tasks at this stage requires appropriate methods of supplying the required amount of binder and mixing water according to the needs of hydration. It should be noted that drilling and mixing technologies are considered as continuous and uniform injection of cement mortar at a water-cement ratio of 0.6…1.5, which is capable of giving the soil concrete strength of about 3.5…4.5 MPa [1,9,12].

The inclusion of a cement-air jet in the operation of drilling and mixing equipment as a factor of programmed injection of cement during the movement of the drill rod and a certain water-cement ratio has the final result of strengthening the soil concrete. In accordance with the degree of enrichment of the soil mixture with cement and the regulated minimum possible water-cement ratio, the strength of the soil concrete and its structure are improved (Fig. 3)

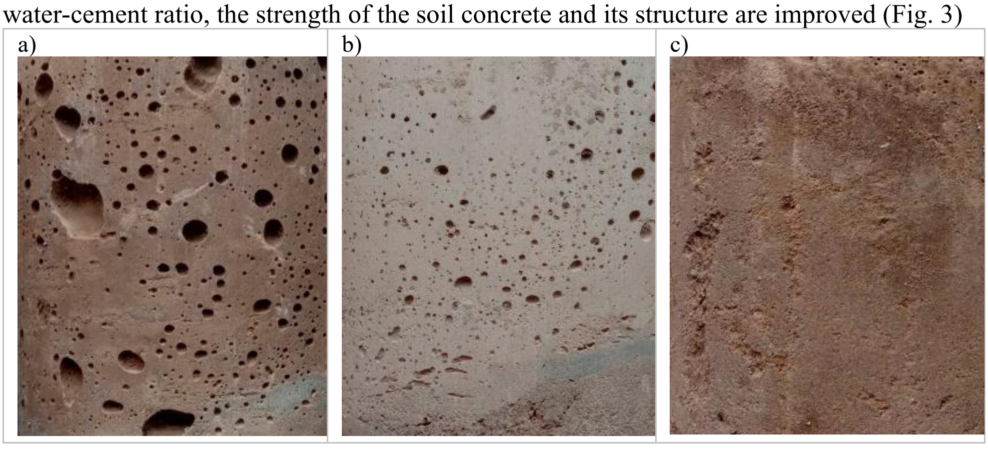

Fig. 3. Macrostructure of soil concrete samples with different cement contents: a) cement content 200 kg; b) cement content 325 kg; c) cement content 400 kg.

On this basis, it is advisable to combine the positive aspects of drilling and jet technologies and use the simplified equipment available in practice with the addition of the inclusion of compressed air energy as a multifunctional one, capable of transporting binder, cutting soil from the walls of the well, mixing cement-soil mixture.

In general, the algorithm of the entire proposed technological process for manufacturing soil-concrete formations using a cement-air jet and a regulated binder content can be presented as follows. At the first stage, a well is prepared in which most of the loosened soil remains without being brought to the surface. With the beginning of the reverse movement and rotation of the drill string, the binder is continuously pumped in using the cement-air jet. If necessary, the specified content can be adjusted using the forward-reverse movement of the drill string. The required water-cement ratio is achieved by metered water supply through the appropriate channel after determining the available soil moisture.

Thus, the designed supply of components occurs during forward or reverse motions, and mixing of the mixture can occur during repeated movement of the drill string. To improve mixing, reverse movement of the drill string with subsequent lifting is possible.

5 Scientific and practical significance

The regularities of the relationships between the parameters of the technology and the characteristics of the manufactured soil concrete piles have been determined, which allows for the purposeful regulation of all processes in accordance with the design requirements for the strength of the soil concrete.

The absence of cement mortar in the technology creates the possibility of reducing the water-cement ratio to the level dictated by the conditions of homogenization of the mixture and hydration of the binder, taking into account the natural soil moisture.

The practical significance of the results lies in reducing energy consumption, the negative impact of highly water-saturated soil on the environment, the need for reinforcement of reinforced soil masses and foundations due to increased strength and cross-section of soil concrete piles.

For practical needs, traditional equipment is suitable without significant reconstruction.

6 Conclusions

The solution to the problem of resource conservation is provided by the use of a cement-air jet according to the hypothesis of the possibility of providing the function of supplying a programmed mass of binder and increasing the cross-section of products in the processes of drilling and mixing, which eliminates the need to use cement mortar and thereby provides an optimal level of water-cement ratio, which results in the prospect of reducing the number of piles with greater bearing capacity, and, accordingly, achieving resource savings and process duration.

The strength of soil concrete increases more than 2 times (up to 12.90 MPa) due to the ability of the jet to provide a programmed binder content, which can exceed 400 kg/m^3 of soil and homogenize the concrete mixture according to a given water-cement ratio as factors for strengthening products and their bearing capacity.

The presence of a cutting function leads to an increase in the cross-section of the manufactured piles, which, together with additional strength, allows for a reduction in the volume of reinforcement and the provision of the underground space with the designed characteristics with less reinforcement.

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